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RESEARCH MEMORANDUM

SUPPLEMENTARY ANALYSIS OF THE DYNAMIC LATERAL STABILITY CHARACTERISTICS OF THE BELL X-2 AIRPLANE AS AFFECTED BY VARIATIONS IN MASS AND AERODYNAMIC PARAMETERS

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

SUPPLEMENTARY ANALYSIS OF THE DYNAMIC LATERAL STABILITY CHARACTERISTICS OF THE BELL X-2 AIRPLANE AS AFFECTED BY VARIATIONS IN MASS AND AERODYNAMIC PARAMETERS

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SUMMARY

The results of recent research, relative to the estimation of the derivative of yawing moment due to rolling C_{n_p}, have been applied to extend a previously reported analysis of the dynamic lateral stability characteristics of the Bell X-2 airplane. The stability calculations indicate that when the values of the derivative C_{n_p} are changed from those indicated by previously established procedures to those indicated by recent research, the predicted period-damping relationship of the airplane becomes less desirable for all the flight conditions investigated. For the high-speed configurations (flaps and gear up), a given change in the value of the derivative C_{n_p} appeared to become of increased importance as the altitude was increased and as the speed of the airplane approached the maximum Mach number investigated (0.87). The calculations indicate that the airplane should meet the USAF requirements for satisfactory period-damping relationship of the lateral oscillation at lift coefficients greater than about 0.5 for the high-speed configuration at altitudes lower than 35,000 feet, but that the airplane in the landing configuration may not meet the requirements at lift coefficients below 1.0.

INTRODUCTION

An analysis of the dynamic lateral stability characteristics of the Bell X-2 airplane has been presented in reference 1. The primary purpose of the analysis was to study the characteristics of the airplane at various altitudes and wing loadings and with certain geometric modifications. Because of uncertainties in estimating some of the parameters, arbitrary variations in the parameters were considered. The range of

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the variations was thought to be large enough to cover probable values of the estimated parameters.

Since the issuance of reference 1, it has been found that the probable value of one of the derivatives - that is, the derivative of yawing moment due to rolling C_{n_p} - may lie considerably beyond the range considered in reference 1. The present paper constitutes an extension of reference 1 to point out the importance of the extended range of this derivative.

SYMBOLS AND COEFFICIENTS

b	wing span, feet
S	wing area, square feet
W	weight of airplane, pounds
h	altitude, feet
V	airplane velocity, feet per second
ρ	mass density of air, slugs per cubic foot
q	dynamic pressure, pounds per square foot $\left(\frac{\rho V^2}{2}\right)$
γ	angle of flight path to horizontal axis, positive in climb, degrees
δ_s	split-flap deflection, degrees
δ_n	nose-flap deflection, degrees
p	rolling angular velocity, radians per second
M	Mach number $\left(\frac{V}{\text{Local speed of sound}}\right)$
$T_{1/2}$	time required for the lateral oscillation to reduce to half amplitude, seconds
T_2	time required for lateral oscillation to double amplitude, seconds

P period of the lateral oscillation, seconds

C_L trim lift coefficient $\left(\frac{W \cos \gamma}{qS}\right)$

C_n yawing-moment coefficient $\left(\frac{\text{Yawing moment}}{qSb}\right)$

C_{n_p} derivative of yawing moment due to roll $\left(\frac{\partial C_n}{\partial \frac{pb}{2V}}\right)$

MASS AND AERODYNAMIC PARAMETERS

The mass parameters used in this investigation are the same as the basic values used in reference 1. All the aerodynamic parameters are also the same as those of reference 1, except for the derivative of yawing moment due to rolling C_{n_p}.

Recent unpublished experimental and theoretical investigations have indicated that the method generally used for estimating C_{n_p} yields values which may differ considerably from experimental results. The source of the difference seems to be in evaluating the contribution of the vertical tail. The estimated values of $C_{n_{p_{tail}}}$ used in reference 1 were obtained from relations presented in reference 2, in which the assumption is made that interference effects of the various component parts of the airplane are zero. Recent test results obtained for several models have indicated that the interference effect of the wing on the tail contribution to C_{n_p} may be very large. A comparison of values of $C_{n_{p_{tail}}}$ for a typical model is presented in figure 1. It can be seen that the estimated values of $C_{n_{p_{tail}}}$ approximate the wing-off measured values but are in poor agreement with the wing-on measured values. This is an indication that consideration of the interference effects of the wing on the tail might account for a large part of the discrepancy in the estimated and measured values of $C_{n_{p_{tail}}}$ for the complete airplane.

A simple explanation of the wing interference effects on the tail is as follows: First, consider a fuselage-tail combination rolling about the longitudinal axis. At low angles of attack, the sidewash angle induced at the vertical tail due to positive roll produces a yawing moment which results in a positive C_{n_p}. When the wing is added to the fuselage-tail combination, a consideration of the trailing vortices in the wake of the rolling wing indicates an induced sidewash in the direction opposite to that induced by the rolling motion of the tail. The resultant effect of considering wing interference is to make the value of $C_{n_{p_{tail}}}$ less positive than that obtained by using the previous method of estimation.

Since the anticipated change in C_{n_p} is larger than the variation of this parameter considered in reference 1, an additional study has been made to determine the effect of the change in C_{n_p} on the stability of the airplane. The period and time to damp to one-half amplitude of the lateral oscillation were calculated by using estimates of C_{n_p} based on recent research. The original values of $C_{n_{p_{tail}}}$ used in the previous calculations, and the new estimated values of $C_{n_{p_{tail}}}$, based on wind-tunnel tests of models somewhat similar to the X-2 airplane, are shown in figure 2. The original and revised values for C_{n_p} for the complete airplane are also presented in figure 2.

RESULTS AND DISCUSSION

Airplane with Flaps and Gear Retracted

The calculated values of the period of the lateral oscillation and the time required for the oscillation to damp to one-half amplitude, using the revised estimates for C_{n_p}, indicate that the stability of the airplane with flaps and landing gear retracted is less satisfactory than that indicated by the original calculations at both sea level and at an altitude of 35,000 feet (fig. 3). The period of the lateral oscillation is decreased only slightly from the previous values in both cases. The time to damp to one-half amplitude is higher than that obtained previously, particularly at low lift coefficients and at the higher altitude. At an altitude of 35,000 feet and the highest Mach number considered (0.87), the time to damp to one-half amplitude is increased from 3.8 seconds to 9.0 seconds.

For several lift coefficients, the calculated values of P and $T_{1/2}$ obtained by considering the original and revised values for C_{n_p} are plotted in figures 4(a) and 4(b) for altitudes of sea level and 35,000 feet, respectively. The calculations are compared with the USAF criterion of the period-damping relationship for satisfactory lateral stability characteristics. At sea level, use of the revised values of C_{n_p} results in values of P and $T_{1/2}$ which, according to the USAF criterion, are unsatisfactory for lift coefficients below about 0.4; whereas, for the original values of C_{n_p}, the values of P and $T_{1/2}$ were satisfactory for lift coefficients as low as 0.3. At an altitude of 35,000 feet, the change in C_{n_p} resulted in values of P and $T_{1/2}$ for lift coefficients below about 0.5 which are on the unsatisfactory side of the boundary, as compared with unsatisfactory values for lift coefficients of about 0.3 and below for the original case.

Curves for the complete range of C_{n_p} investigated for the airplane with flaps and gear retracted are presented for $C_L = 0.316$ in figure 5, which indicates that the extension of the range of C_{n_p} values considered herein has a rather large unfavorable effect on the period-damping relationship.

Airplane with Flaps and Gear Lowered

In order to determine the effect of the revised estimates of C_{n_p} on the landing characteristics of the airplane, values of P and $T_{1/2}$ were calculated for several lift coefficients at sea level with flaps and landing gear lowered. The calculations were made for two wing-loading conditions and the results are presented in figures 6(a) and 6(b). From the figures it is apparent that the change in C_{n_p} has an unfavorable effect on the stability of the airplane. The values of the period decrease slightly for both of the wing loadings considered. In both cases the rate of damping is decreased, and for the lower wing loading, the decrease in damping becomes larger as the lift coefficient decreases.

For a wing loading of 33.3 pounds per square foot, the period-damping relationship obtained by using the revised values for C_{n_p} failed to satisfy the USAF criterion for all lift coefficients investigated, whereas with the original estimates of C_{n_p}, the airplane was satisfactorily stable for lift coefficients greater than about 0.95 (fig. 7). For the high-wing-loading condition, only those values of P and $T_{1/2}$ corresponding to lift coefficients greater than 0.9 are on the satisfactory side of the boundary when the new C_{n_p} values are used, as compared with lift coefficients of 0.8 or higher for the original values of C_{n_p}.

Curves for the complete range of C_{n_p} investigated for the airplane with flaps and gear lowered are presented in figure 8 for $C_L = 1.0$. As in the case of the airplane with flaps and gear retracted, the extension of the range of C_{n_p} values in the negative direction is shown to have an appreciable unfavorable effect on the period-damping relationship.

CONCLUSIONS

Results of recent research on the evaluation of the derivative of yawing moment due to rolling C_{n_p} have been utilized in calculations of the dynamic lateral stability characteristics of the Bell X-2 airplane at Mach numbers up to 0.87. The results of the calculations have led to the following conclusions:

1. When values of the derivative of yawing moment due to rolling C_{n_p} are changed from those indicated by previously established procedures to those indicated by the results of recent research, the predicted period-damping relationship of the airplane becomes less desirable for all the flight conditions investigated.

2. For the high-speed configuration (flaps and gear up) a given change in the value of the derivative C_{n_p} appeared to become of increased importance as the altitude is increased and as the speed of the airplane approaches the maximum Mach number investigated (0.87).

3. The calculations indicate that the airplane should meet the USAF requirements for satisfactory period-damping relationship of the lateral oscillation at lift coefficients greater than about 0.5 for the high-speed configuration at altitudes lower than 35,000 feet, but that the airplane in the landing configuration may not meet the requirements at lift coefficients below 1.0.

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1. Michael, W. H., and Queijo, M. J.: Analysis of the Dynamic Lateral Stability Characteristics of the Bell X-2 Airplane as Affected by Variations in Mass, Aerodynamic, and Dimensional Parameters. NACA RM L9G13, 1949.

2. Bamber, Millard J.: Effect or Some Present-Day Airplane Design Trends on Requirements for Lateral Stability. NACA TN 814, 1941.

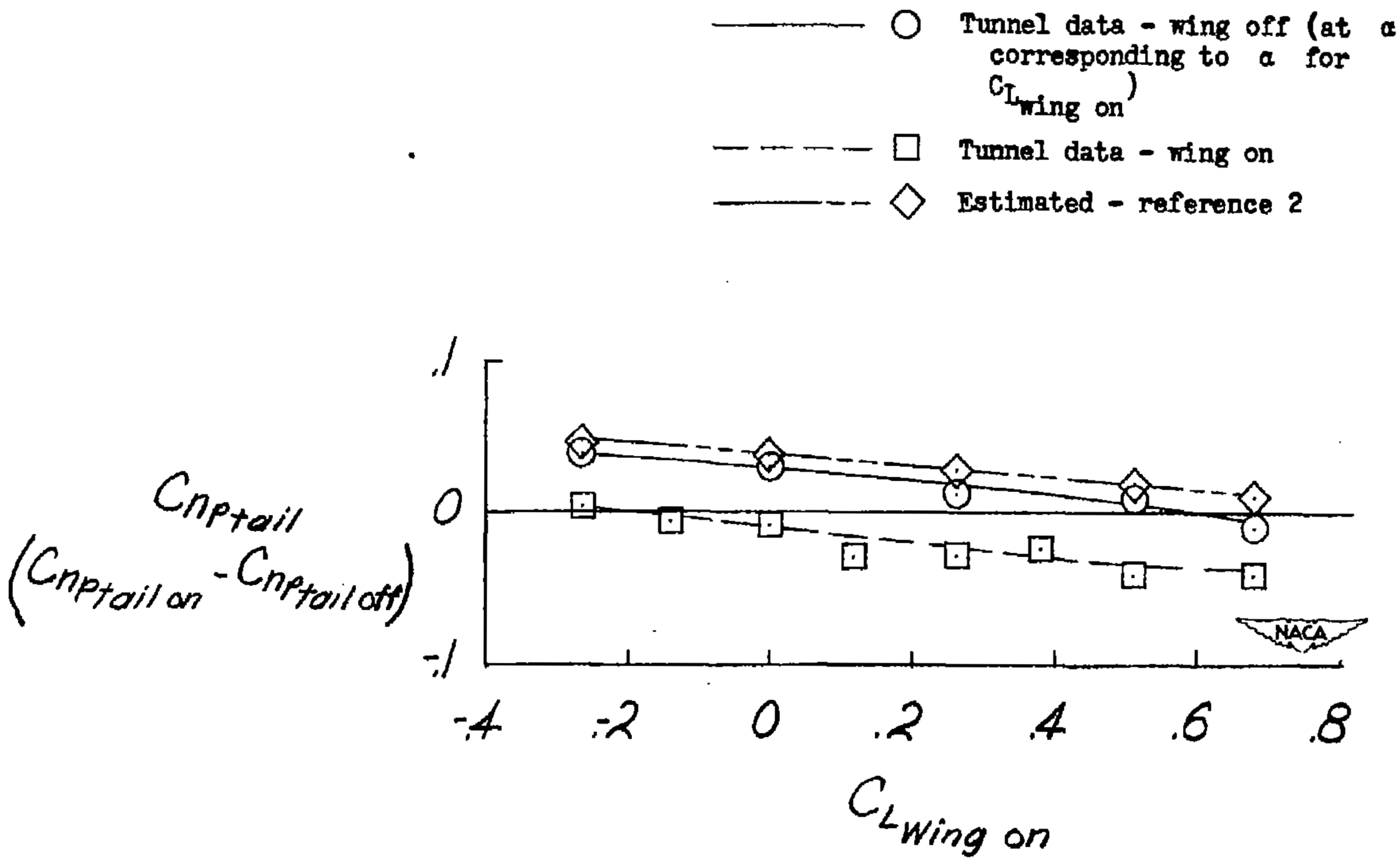
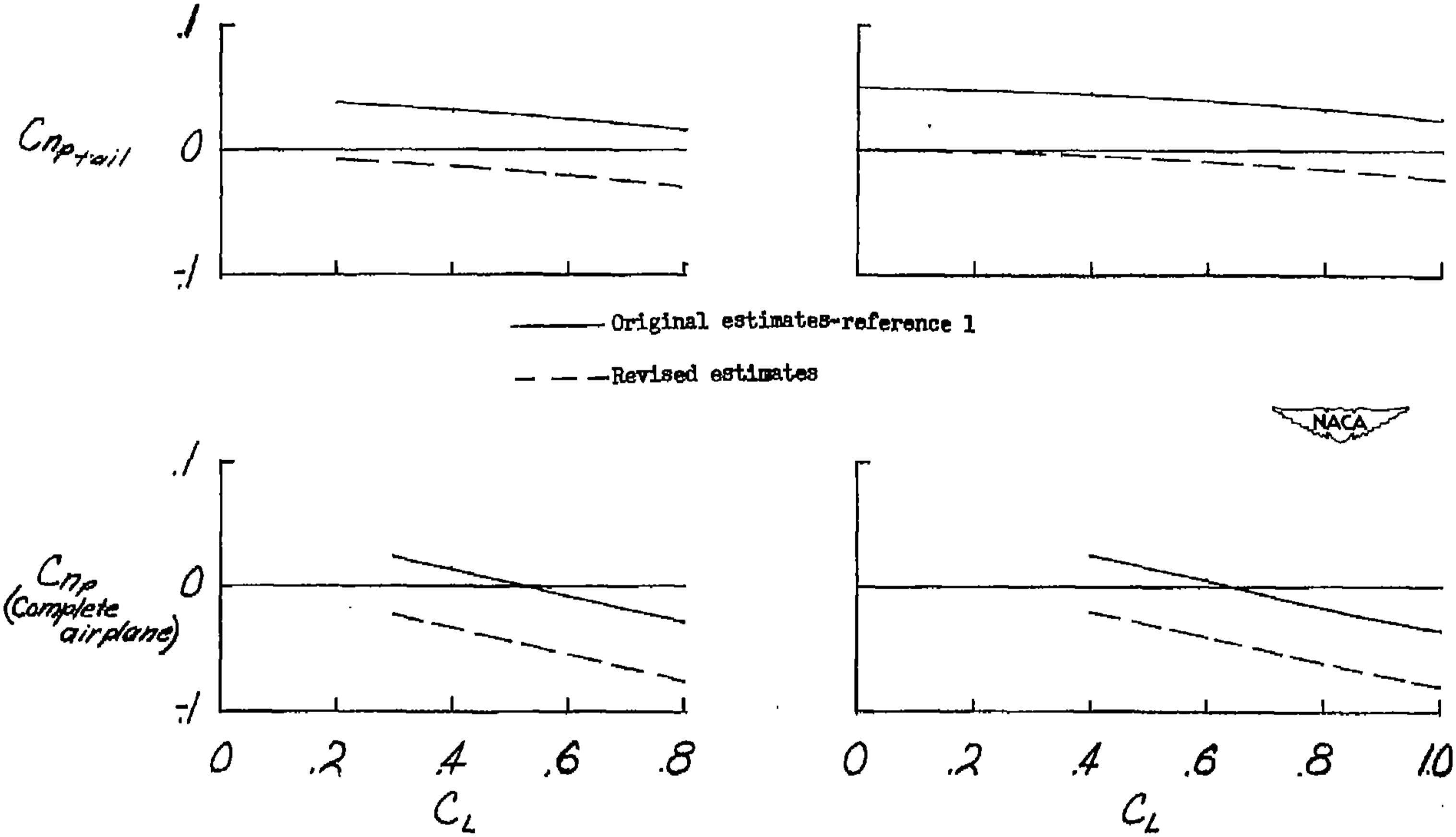


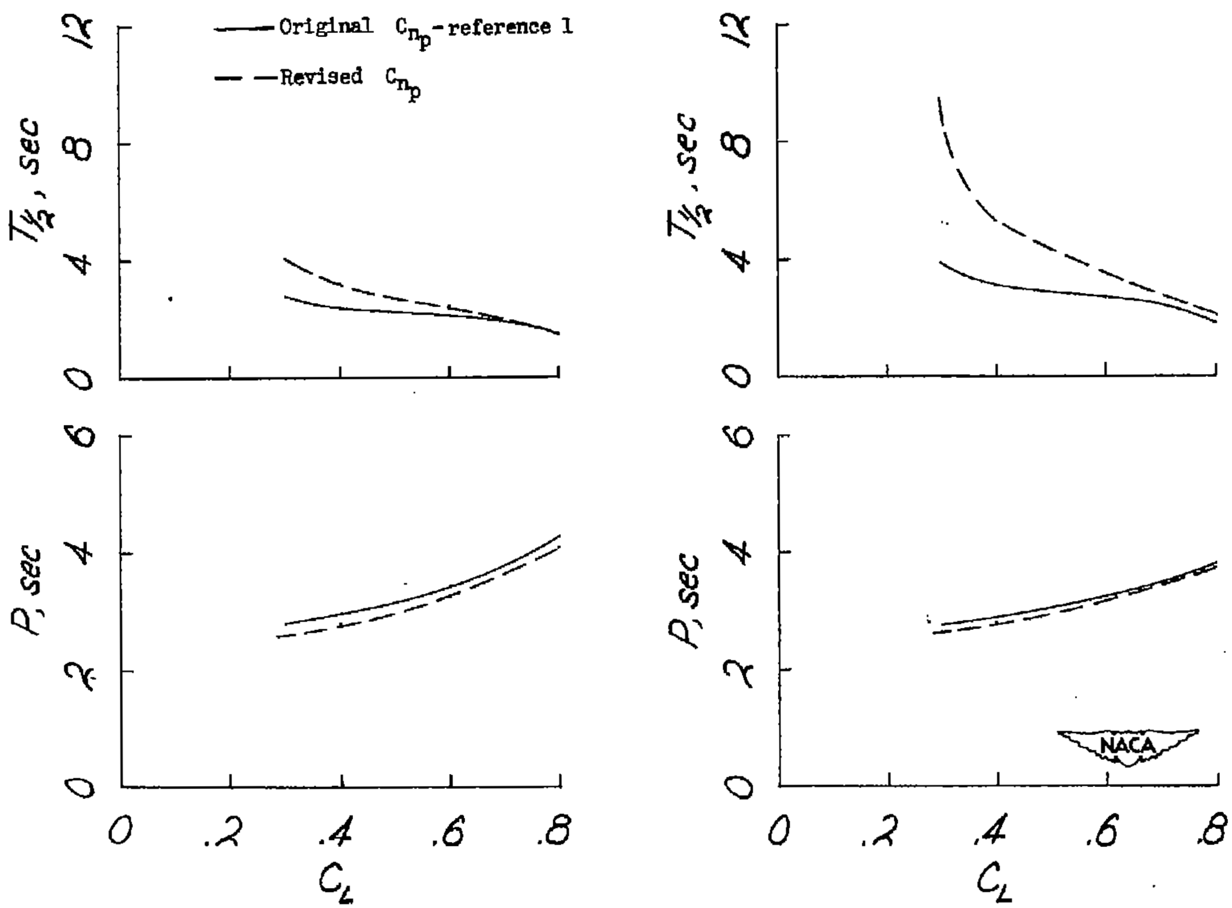
Figure 1.- Effect of wing on tail contribution to C_{n_p} for a typical model.



(a) Flaps and gear retracted.

(b) Flaps and gear lowered.

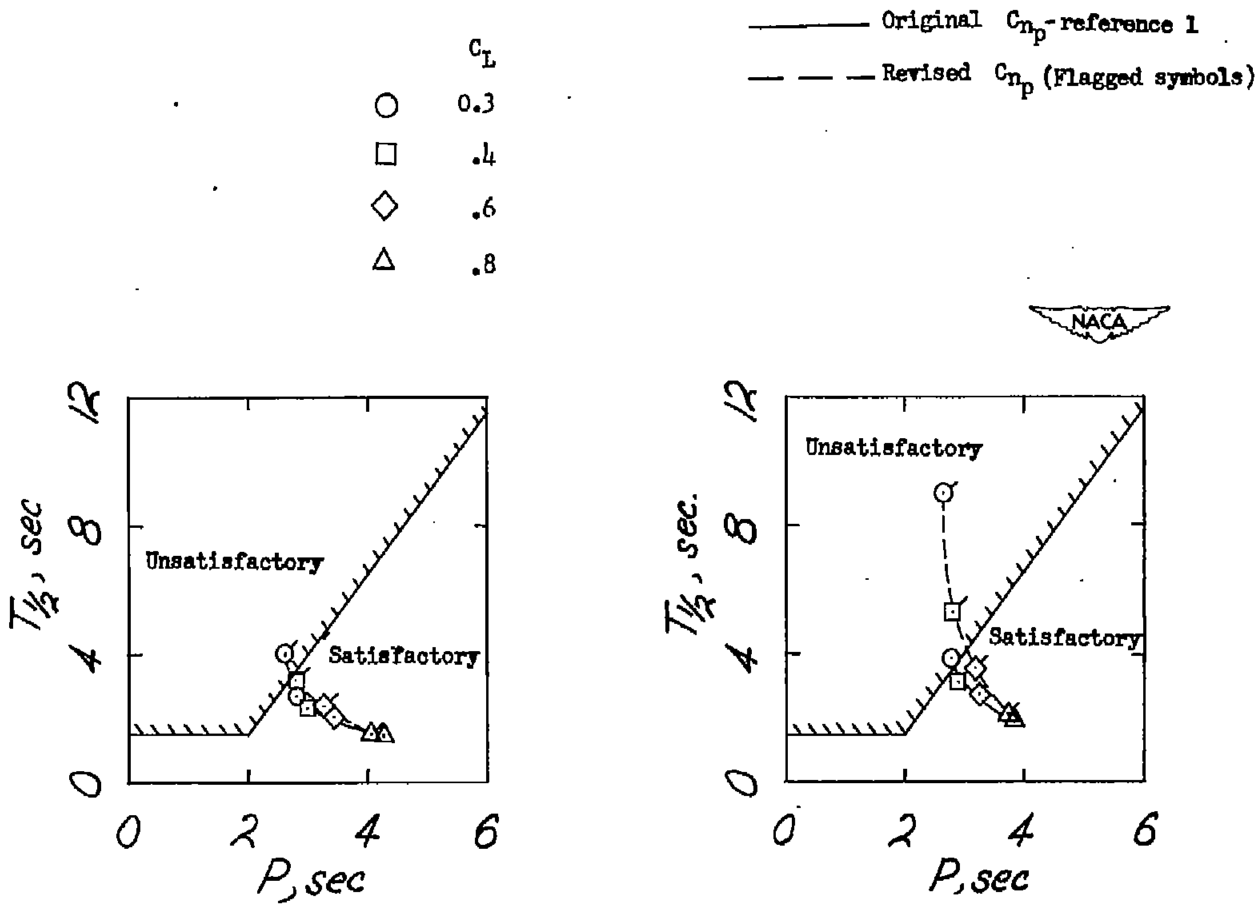
Figure 2.- Original and revised estimates of $C_{n_{p_{tail}}}$ and C_{n_p} for Bell X-2 Airplane.



(a) Sea level.

(b) 35,000 feet.

Figure 3.- Period and time to damp to one-half amplitude for Bell X-2 airplane calculated with original and revised estimates of C_{n_p}. Flaps and gear retracted. $\frac{W}{S} = 79.4$ pounds per square foot.



(a) Sea level.

(b) 35,000 feet.

Figure 4.- Comparison with USAF criterion of the period-damping relationship of the Bell X-2 airplane calculated with original and revised estimates of C_{n_p}. Flaps and gear retracted. $\frac{W}{S} = 79.4$ pounds per square foot.

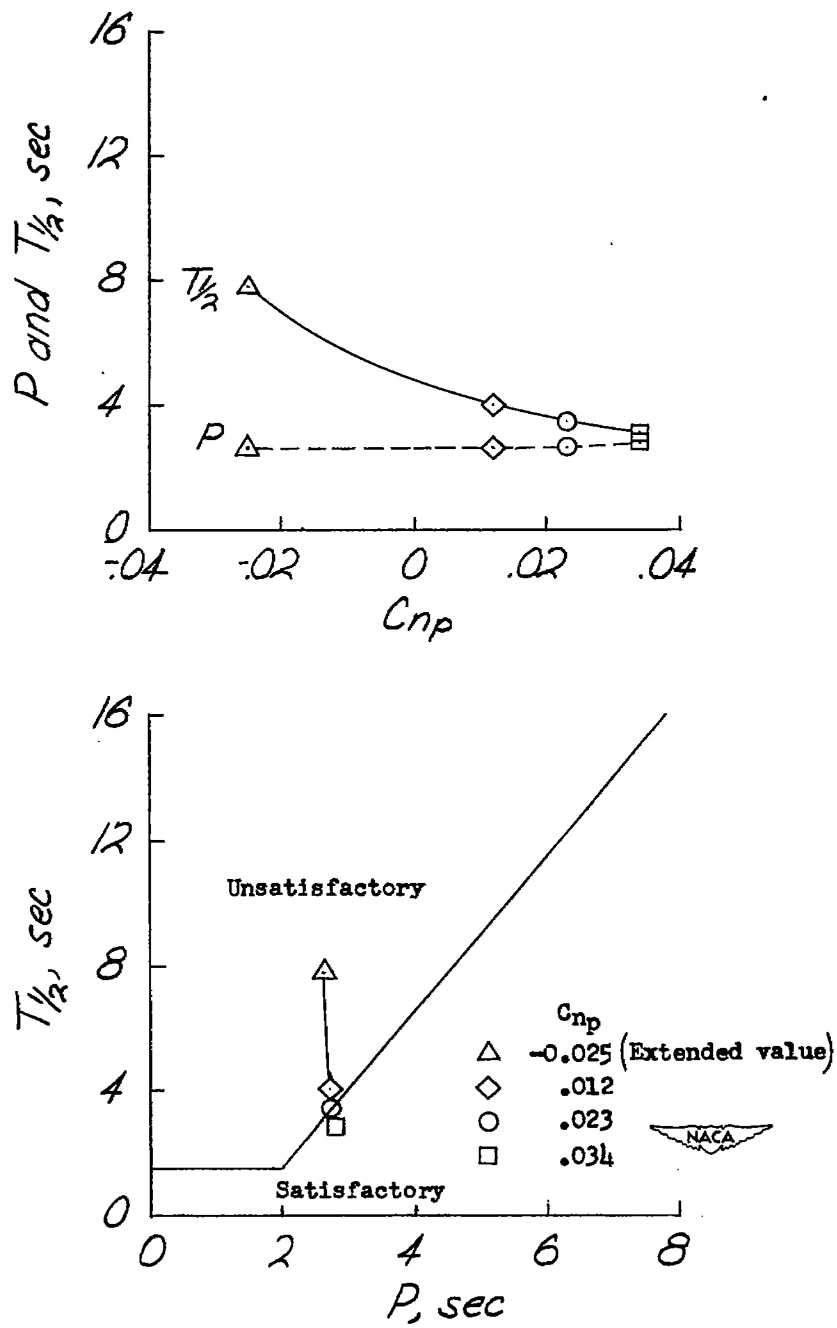
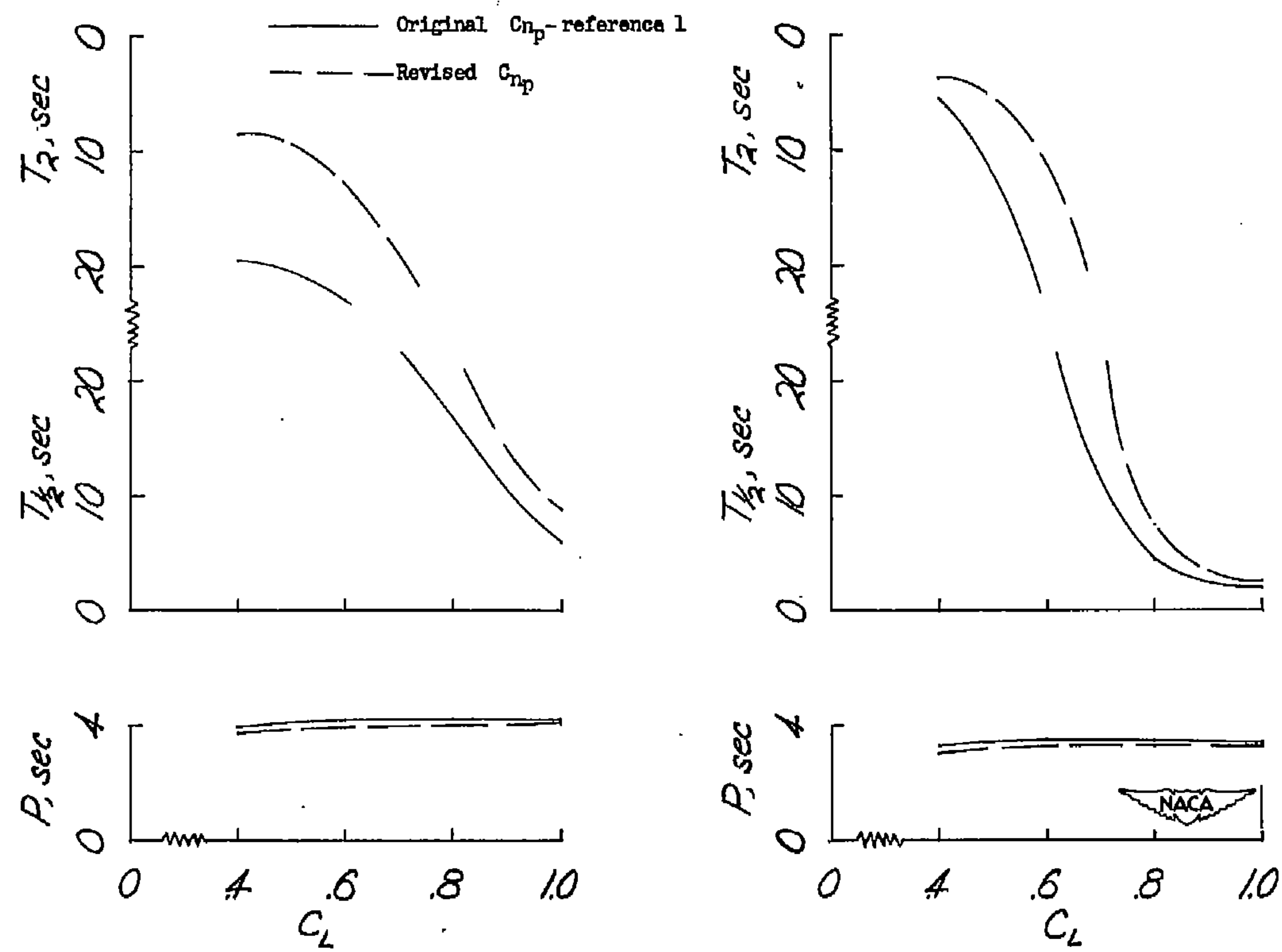


Figure 5.- Effects of variation of C_{n_p} on the period and damping, and a comparison with the USAF criterion. Flaps and gear retracted; $\frac{W}{S}$ = 79.4 pounds per square foot; h = 35,000 feet; M = 0.85; C_L = 0.316.



(a) $\frac{W}{S}$ = 33.3 pounds per square foot.

(b) $\frac{W}{S}$ = 79.4 pounds per square foot.

Figure 6.- Period and time to damp to one-half amplitude for Bell X-2 airplane calculated with original and revised estimates of C_{n_p}. Flaps and gear lowered; $\delta_n = 30^\circ$; $\delta_s = 55^\circ$; sea-level flight.

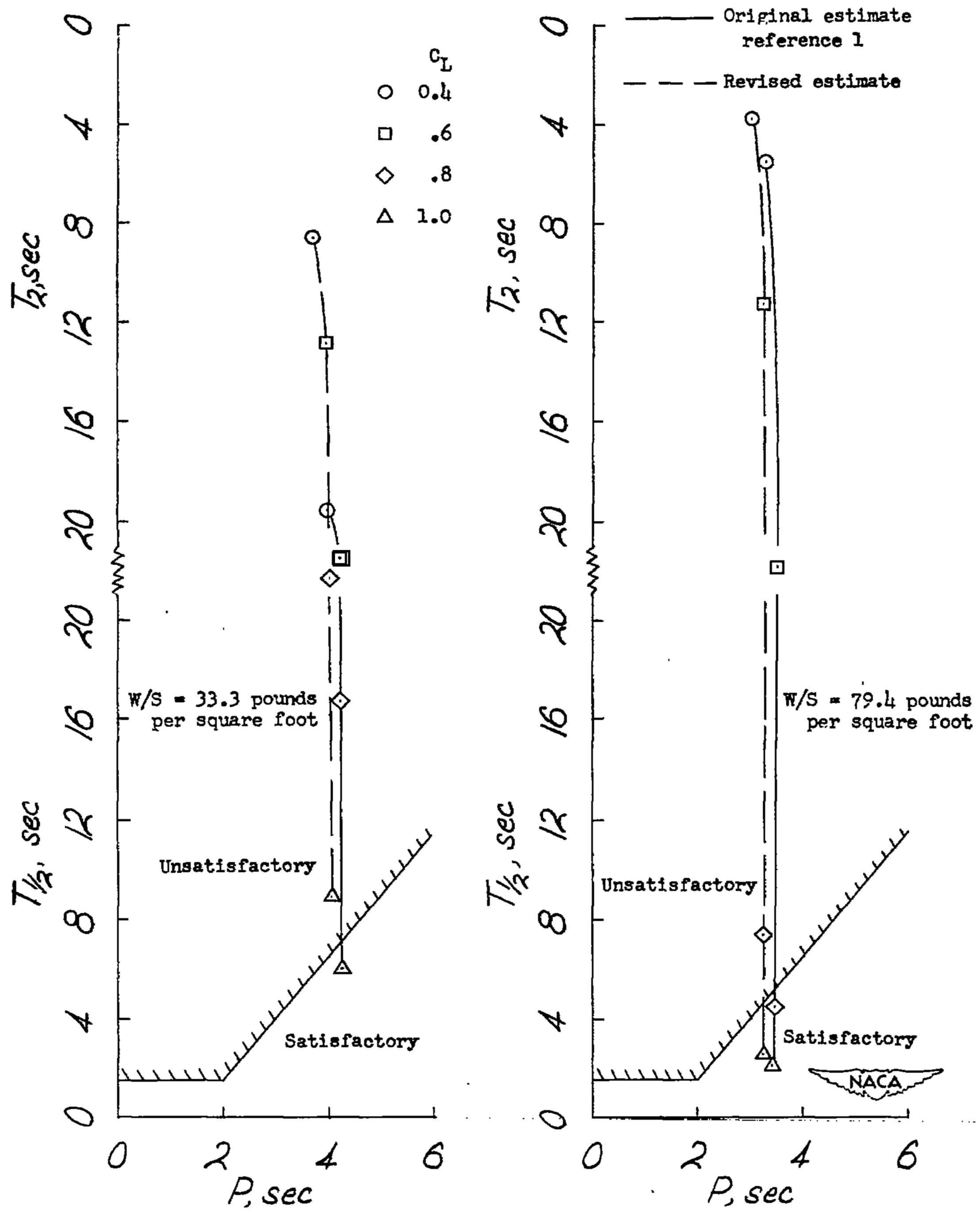


Figure 7.- Comparison with USAF criterion of the period-damping relationship of the Bell X-2 airplane calculated with original and revised estimates of C_{n_p}. Flaps and gear lowered; $\delta_n = 30^\circ$; $\delta_s = 55^\circ$; sea-level flight.

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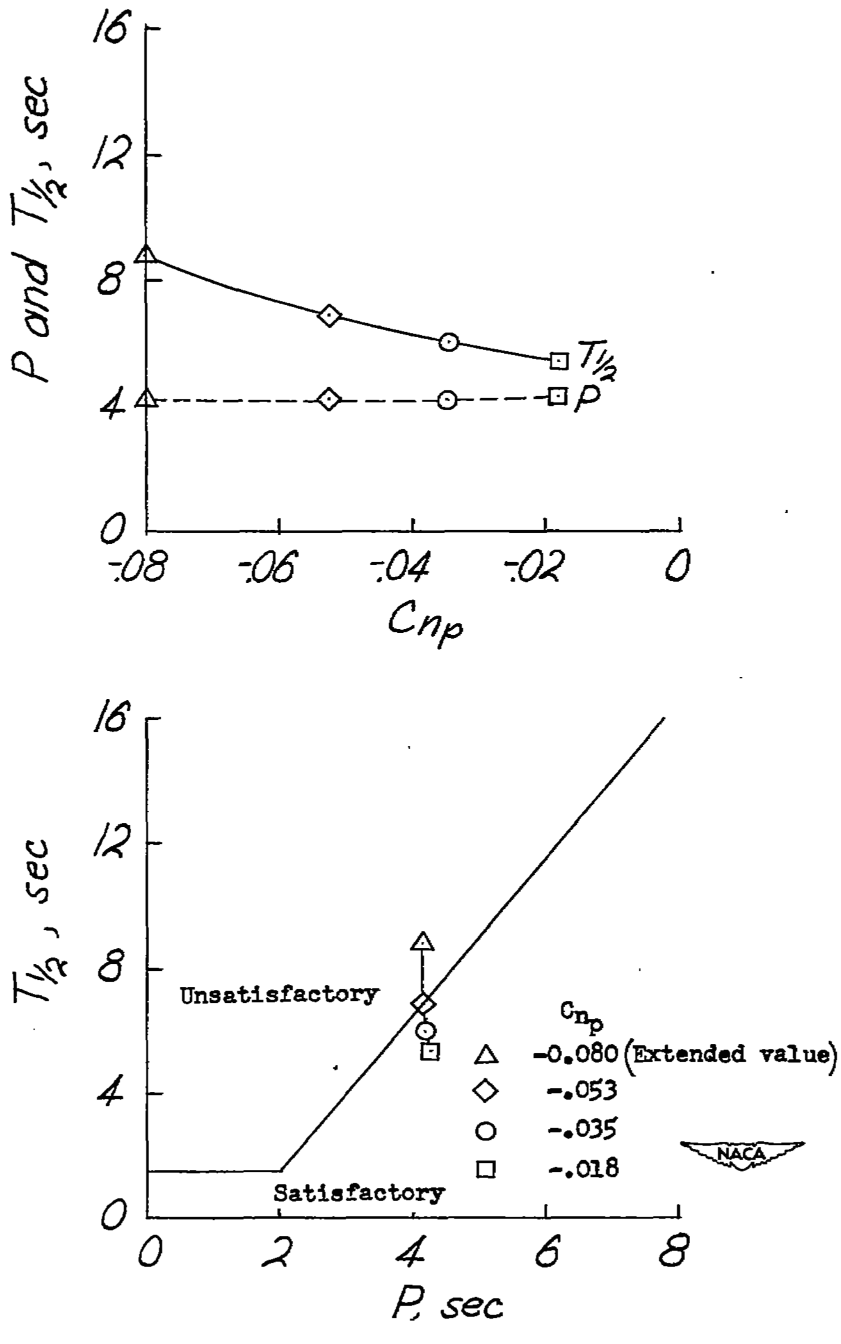

Figure 8.- Effects of variation of C_{n_p} on the period and damping, and a comparison with the USAF criterion. Flaps and gear down; $\frac{W}{S}$ = 33.3 pounds per square foot; $\delta_n = 30^\circ$; $\delta_s = 55^\circ$; sea-level flight; $C_L = 1.0$.

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